KEY TECHNICAL CONSIDERATIONS FOR SUCCESSFUL HYDRAULIC FRACTURING OF HPHT WELLS

Visegrád, 21 November 2013

Wei Kan Wang, Schlumberger

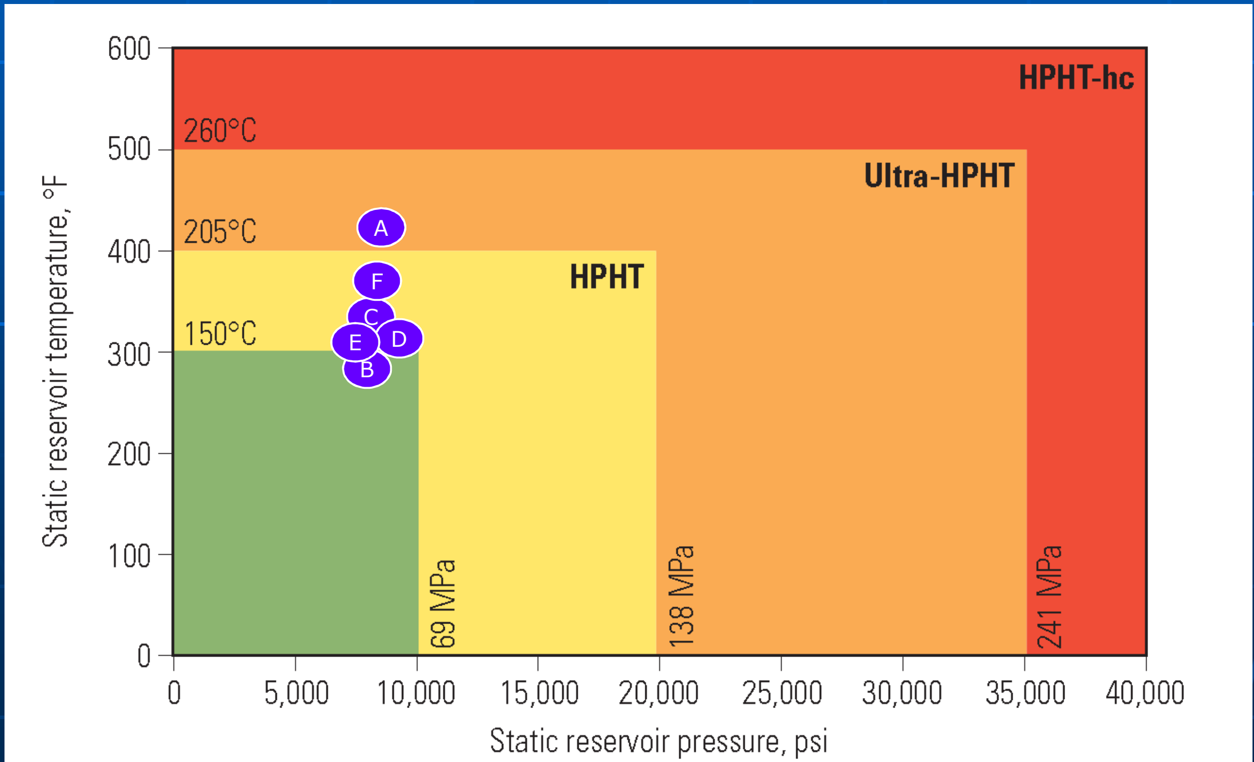
HPHT Wells

- Most common HPHT definition –

  Pressure > 10,000 psi (690 bar)

  Temperature > 300 ºF (149 ºC)

- Most tight gas developments onshore Europe are HPHT condition



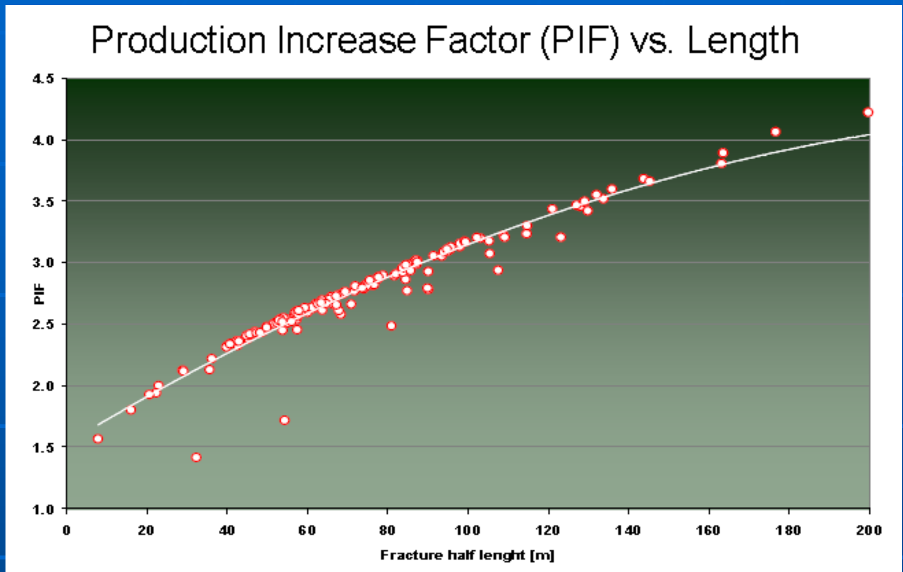
- A Berettyóújfalu (Beru)
- B Varnhorn
- C Goldenstedt
- D Sohlingen
- E Oythe
- F HOD

Setting the Scene

- **Reservoir**
  - Depth – ~ 3700 - 4200 m TVD
  - Lithology – Tight Sandstone
  - Temperature – ~ 150 – 210 ºC
  - Reservoir Pressure – ~ 600 – 700 bar
  - Permeability –
  - Porosity –
  - Reservoir Fluids – Gas, sometimes with condensate
  - Contaminants – may contain CO_2, H_2S

- **Production**
  - Pre- Fracturing –
  - Post- Fracturing –

HPHT Tight Gas: Hydraulic Fracturing



Saih Rawl Database (Oman)

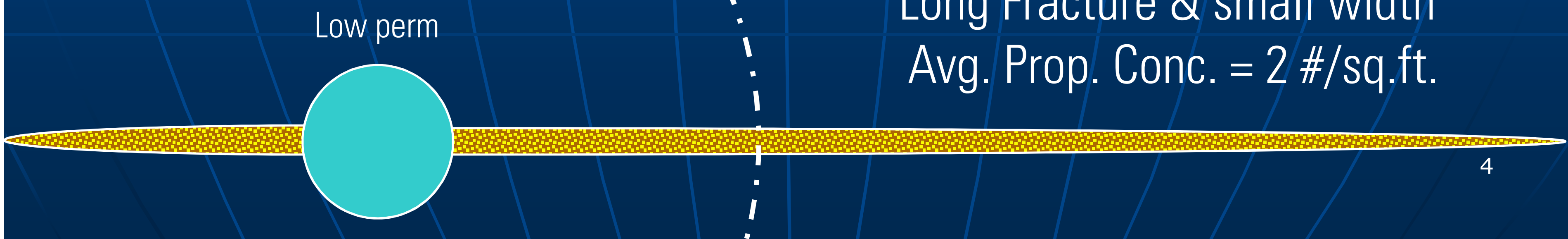
$$F_{cd} = \frac{k_f w}{k x_f}$$

K_f: Prop Pack Perm
W: Fracture Width
K: Formation Perm
X_f: Frac Half Length

- Fracture Length (Xf) is inversely proportional to formation perm (k)

Effective Wellbore Radius ~ 0.5 X_f (F_{cd} > 10)

Long Fracture & small width
Avg. Prop. Conc. = 2 #/sq.ft.



Challenges of HPHT Well Fracturing

HT

- Materials designed for high/ultra temperature applications:
  - Fracturing fluids
  - Completions, and zonal isolation
  - Perf guns, Testing...etc

HP

- Materials designed for high pressure / stress applications:
  - Proppants
- An integrated workflow based on reservoir characterization:
  - MEM: predicting the stress
  - Fracturing stage placement / zonal coverage (stress profile)
- Minimize surface treating pressure:
  - Optimized perforation strategy in high stress zones
  - Breakdown / Diagnostic injections
  - Fluids initiatives (low friction, high density..etc)

Solutions for High Temperature

HT Fracturing Fluids Requirement

- Place all proppant without screen-out
- Robust fluid design with location water, chem
- Maximize fracture half length

Ease of Design

- Maintain leakoff control
- Delayed viscosity generation
- Maximized Clean-up/Conductivity

Fluid Efficiency

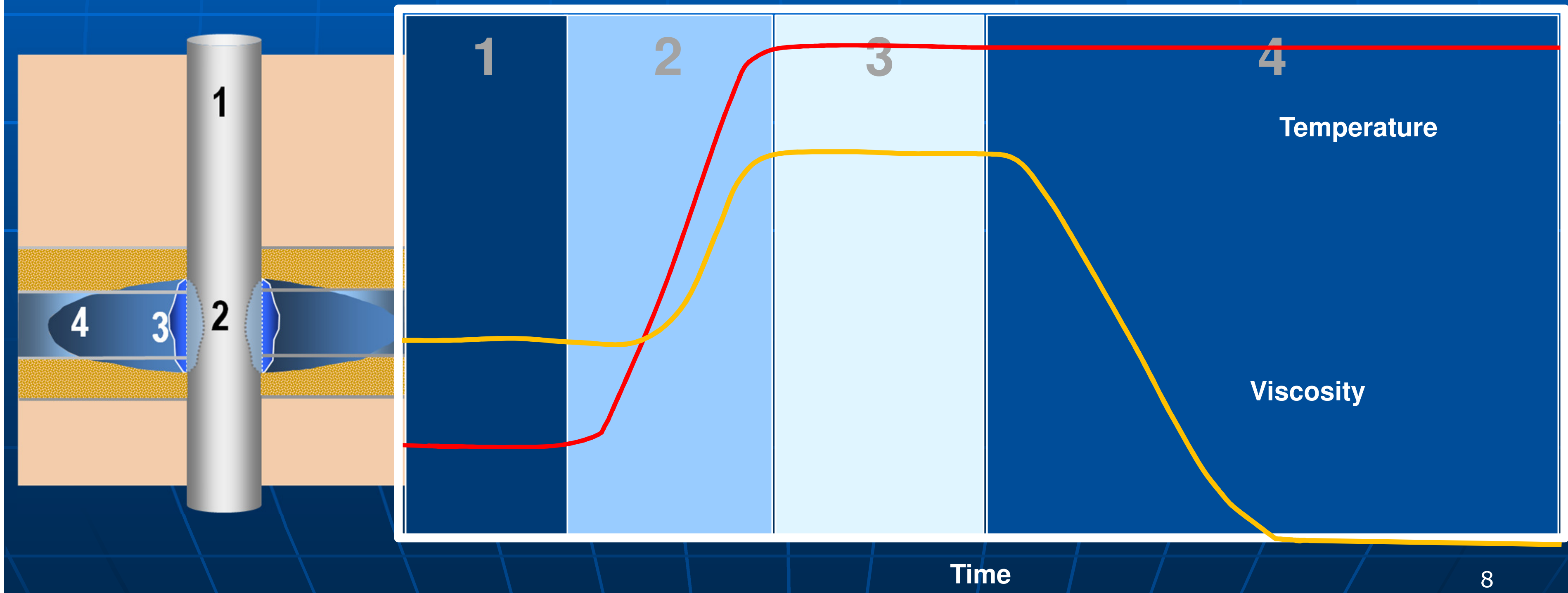
- Proppant Suspension @ BH Temperature
- Retained Viscosity at Pressure
- Shear–Rate Regimes

Stability

HPHT Reservoirs exacerbate BH challenges in fracturing, require unique, robust technological advances

Desired Viscosity Profile

1. Low-intermediate viscosity in tubing
2. Complete crosslinking at high temperature (propagate frac, suspend proppant)
3. Sufficient fluid stability with time at high temperatures
4. Reduced fluid viscosity (break) after proppant is placed



High / Ultra Temperature Fluids

Temperature Ratings	300°F	325°F	350°F	375°F	400°F	425°F	450°F
	149°C	163°C	177°C	191°C	204°C	218°C	232°C

- **Borate Crosslinked Fluids**

  - Requires water introduction for formation cool down
  - Fluid at tip may not be able to grow in length
  - Low prop pack conductivity due to high gel loading

- **CMHPG Zirconium Crosslinked Fluids**

  - Performance of early version CMHPG fluid usually compromised for:
    - Shear –sensitivity
    - Crosslink too early / too late
  - Later generation CMHPG fluid:
    - Overcome shortage of earlier version
    - Most commonly applied in onshore Europe HT wells recent years
    - Stretched in ultra temp wells

- **Synthetic Guar Fluids**

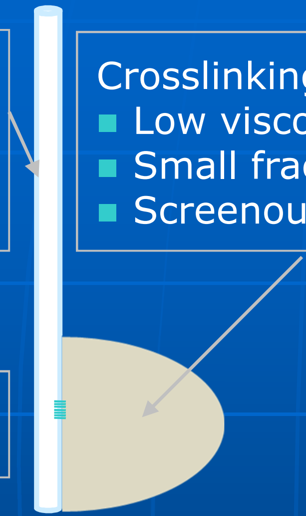
  - Developed for ultra temperatures: 350 – 450 ºF

ThermaFRAC*

SAPPHIRE XF

ThermaFRAC* Fluid (200 - 375 ºF)

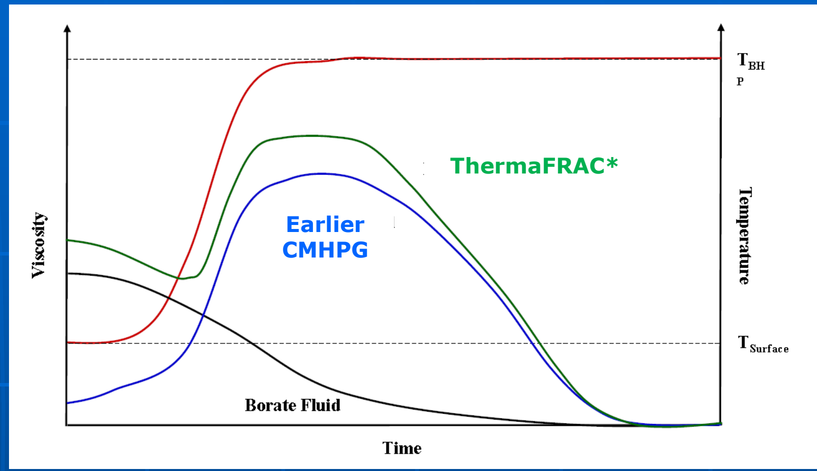
Crosslinking too early
- High-friction
- Shear degradation
- Screenout



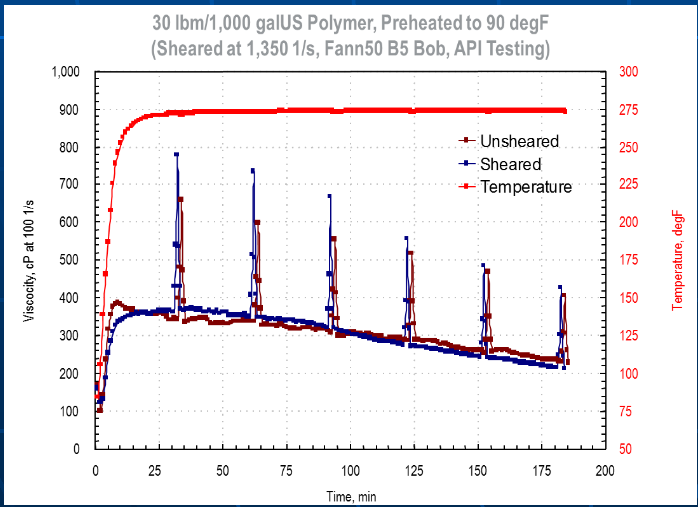
Crosslinking too late
- Low viscosity
- Small fracture width
- Screenout

What is the temperature at the perforations?

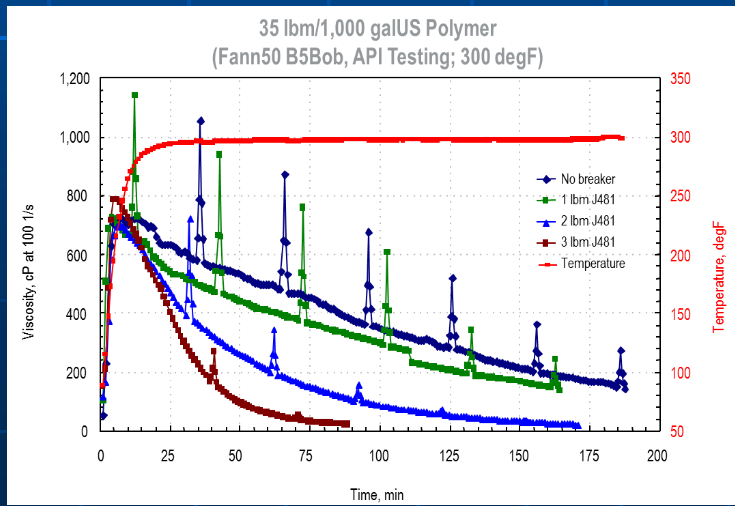
Viscosity Development



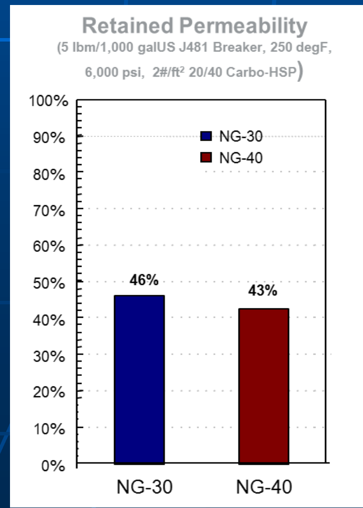
Shear Tolerance



Controllable Viscosity

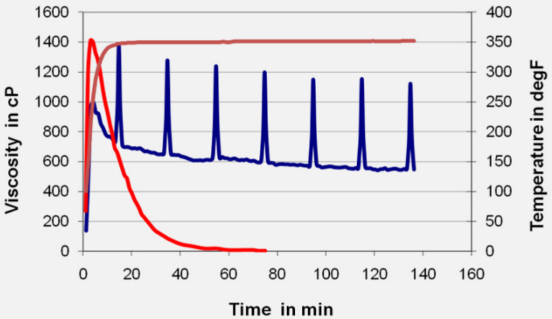


Retained Perm

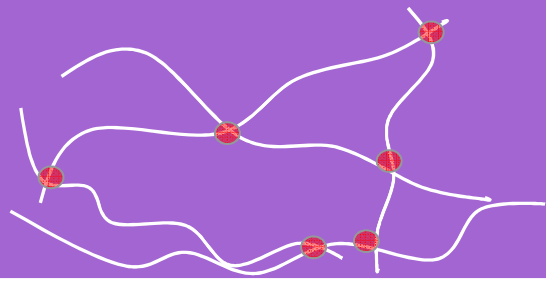


SAPPHIRE XF* Fluid (350 - 450ºF)

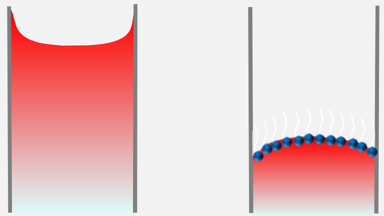
Polymer
- Synthetic polymer for HT applications



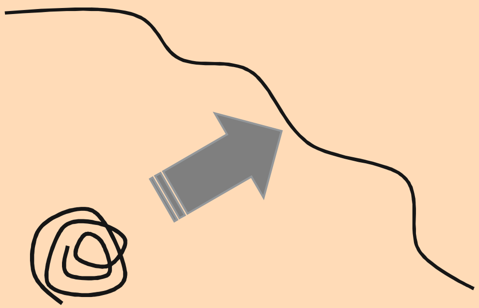
Crosslinker & Delay
- HT crosslinker component
- Combined approach of chemical & temperature delay



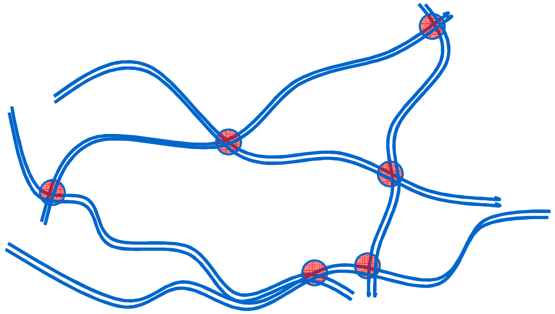
Surfactants
- Surfactants acting as flow back aids to minimize risk of water block



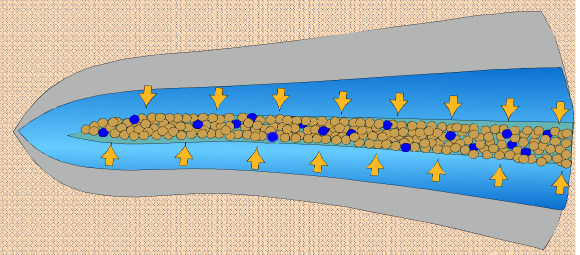
pH Buffer
- Ensuring fast polymer hydration for high pump rate



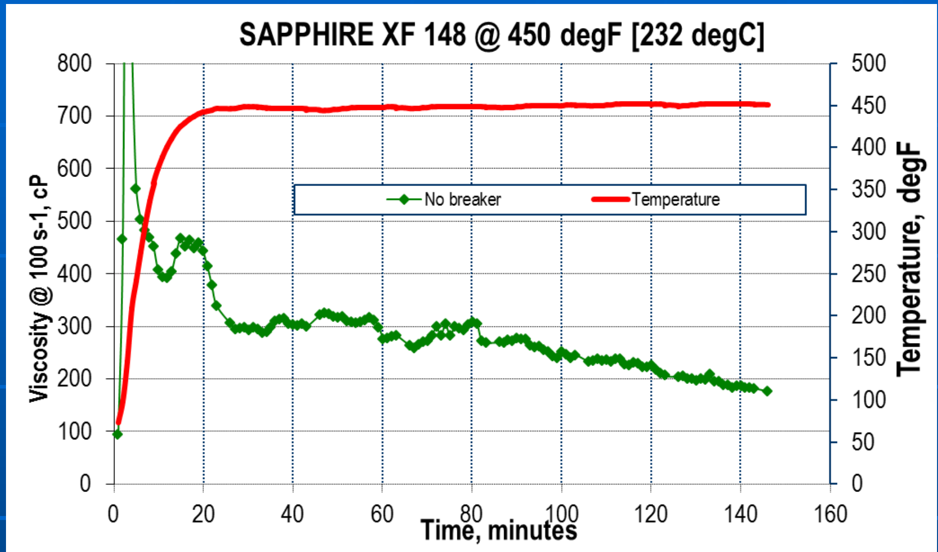
Temperature stabilizer
- Chemical stabilization of polymer for high temperature application

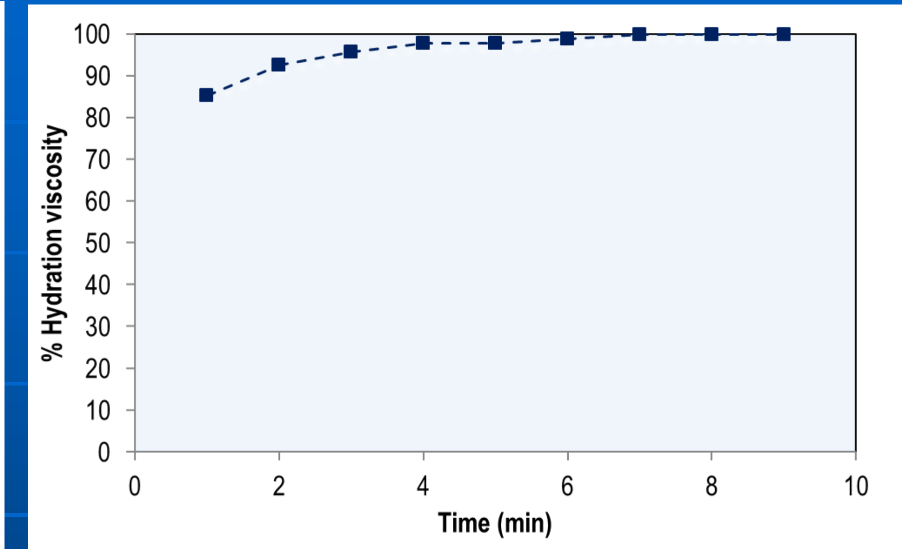


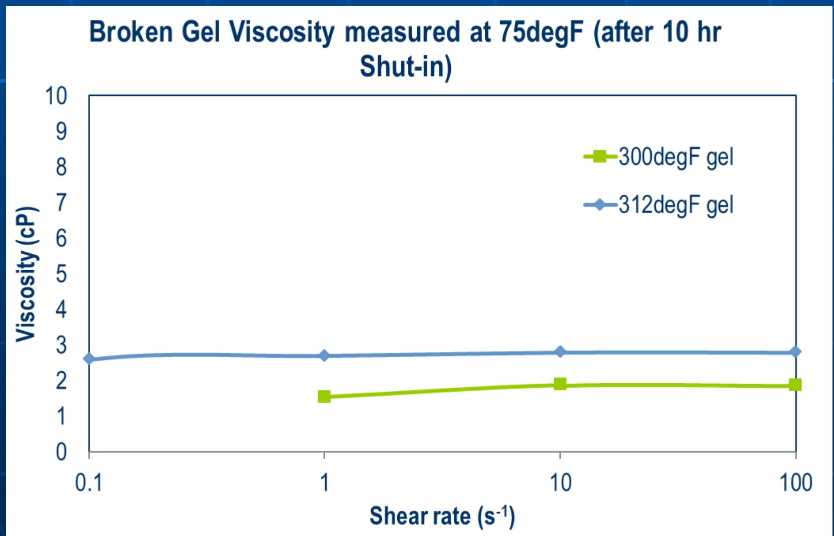
Breaker
- Active breaker & encapsulated breaker for controlled viscosity reduction



SAPPHIRE XF* Fluid (350 - 450ºF)



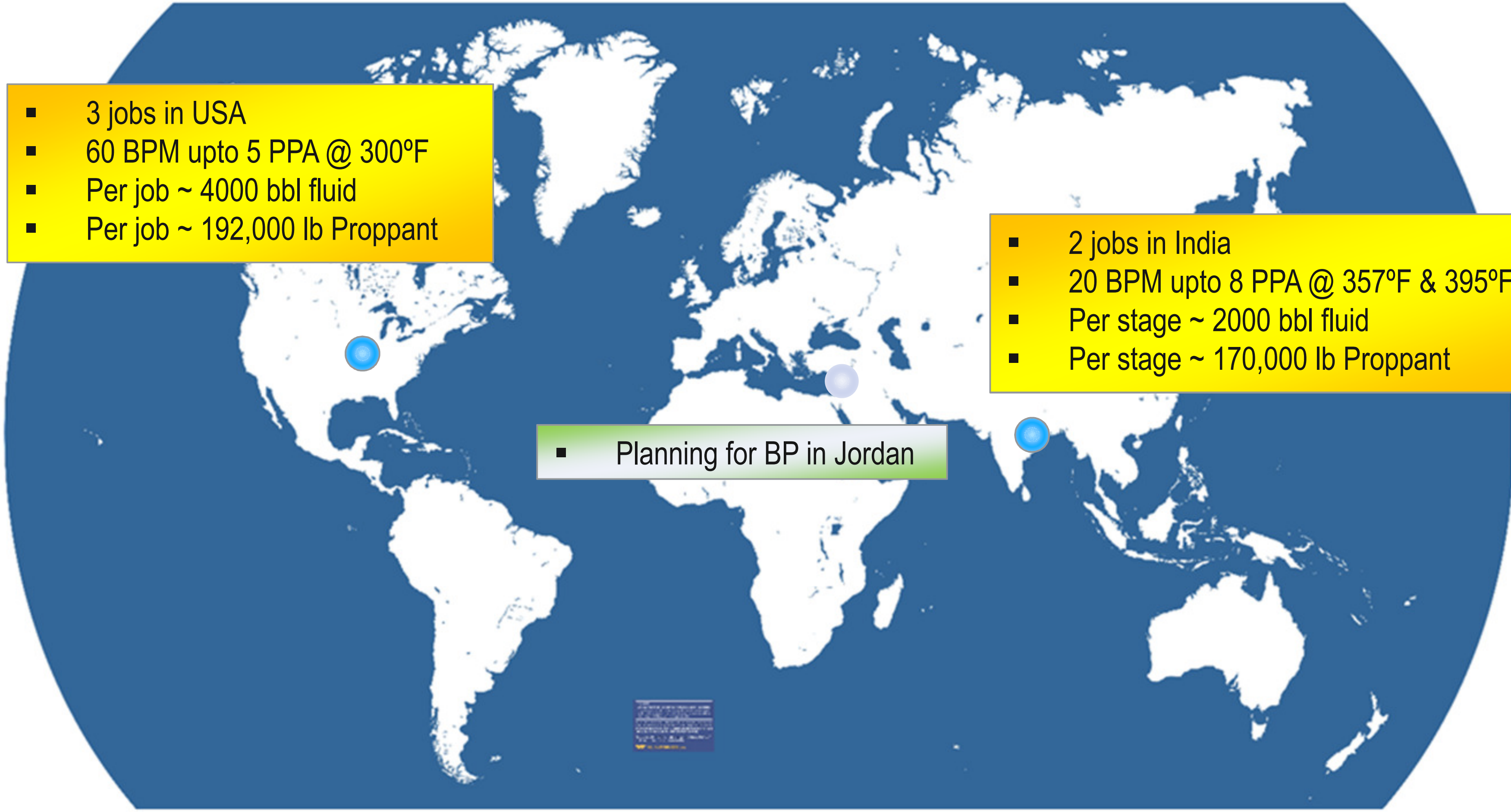




Temperature degF	Fluid Description	Proppant	Breaker [lbm/1000 galUS]	Retained Conductivity
400	SAPPHIRE XF48	20/40 Carbo HSP	10 (J481) + 10 (J490)	40%
350	SAPPHIRE XF48	20/40 Carbo HSP	10(J481) + 10 (J490)	30%
325	SAPPHIRE XF40	40/70 sand	5 (J481) + 5 (J490)	59%
300	SAPPHIRE XF35	20/40 Carbo HSP	5 (J481) + 5 (J490)	56%

Test conditions: 5000 psi, 2 lb/ft^2

SAPPHIRE XF* Fluid (350 - 450ºF)



- 3 jobs in USA
- 60 BPM upto 5 PPA @ 300ºF
- Per job ~ 4000 bbl fluid
- Per job ~ 192,000 lb Proppant

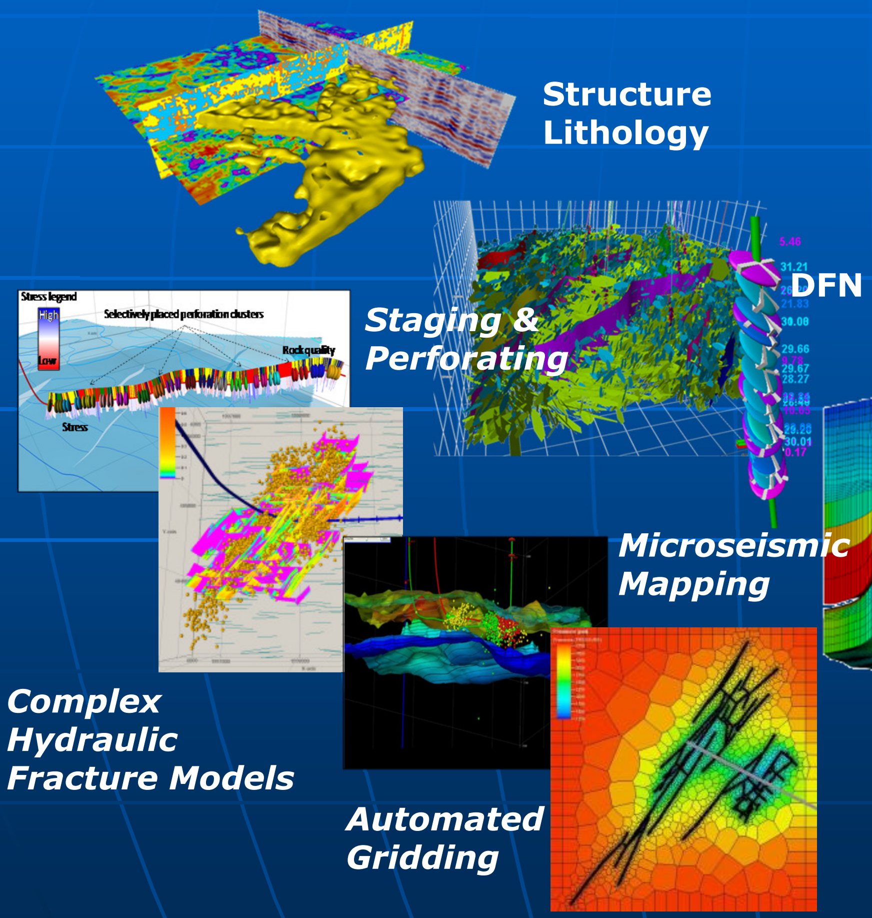
- Planning for BP in Jordan

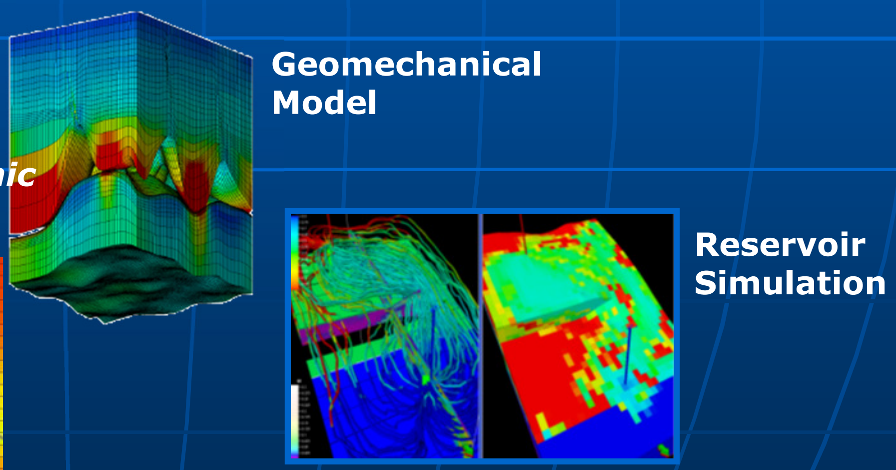
- 2 jobs in India
- 20 BPM upto 8 PPA @ 357ºF & 395ºF
- Per stage ~ 2000 bbl fluid
- Per stage ~ 170,000 lb Proppant

Solutions for High Pressure

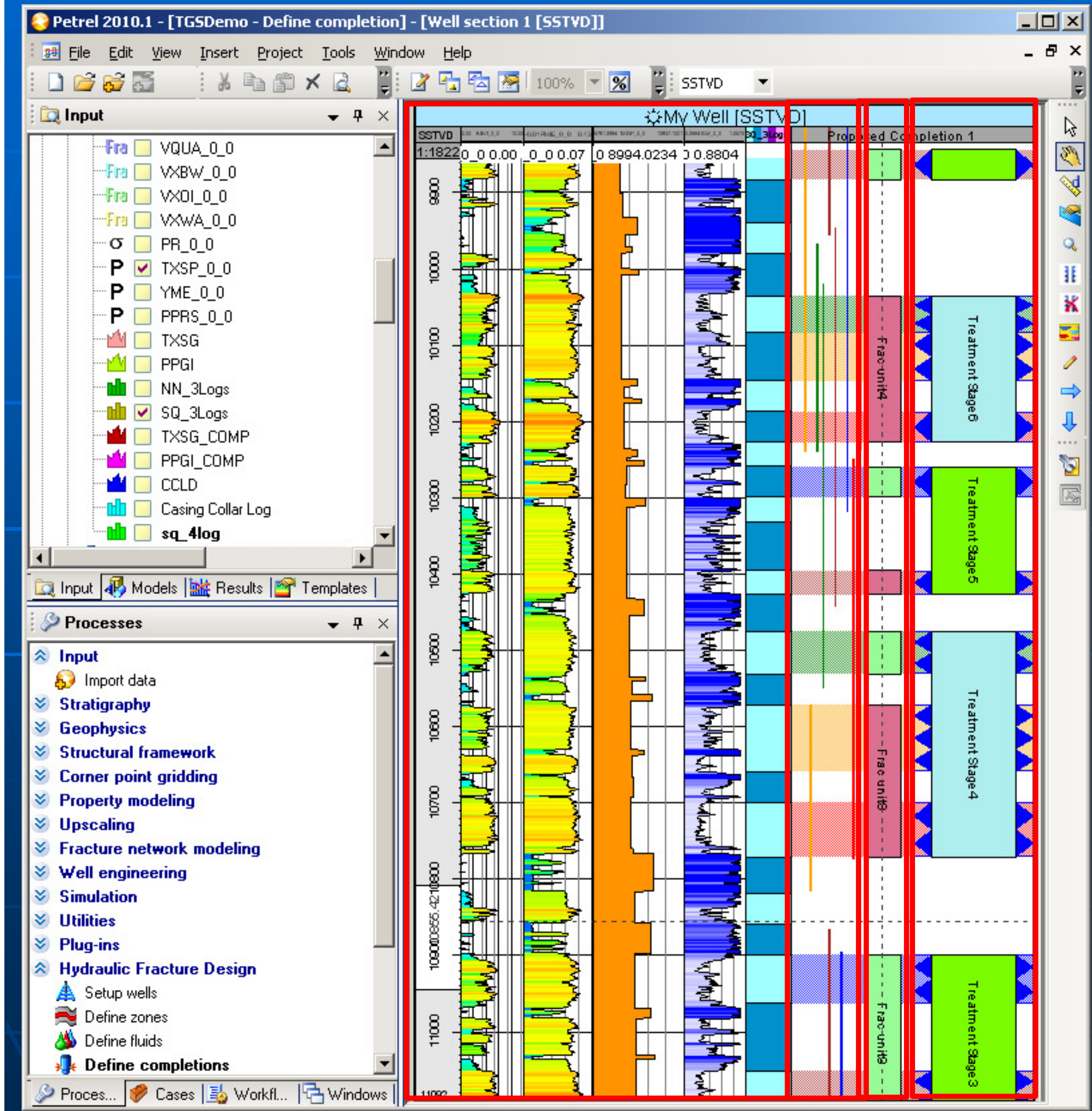
Reservoir-Centric Integrated Workflow

- Integrated workflow supports seismic -to-simulation modeling
- Hydraulic Fracturing permanently alters the reservoir





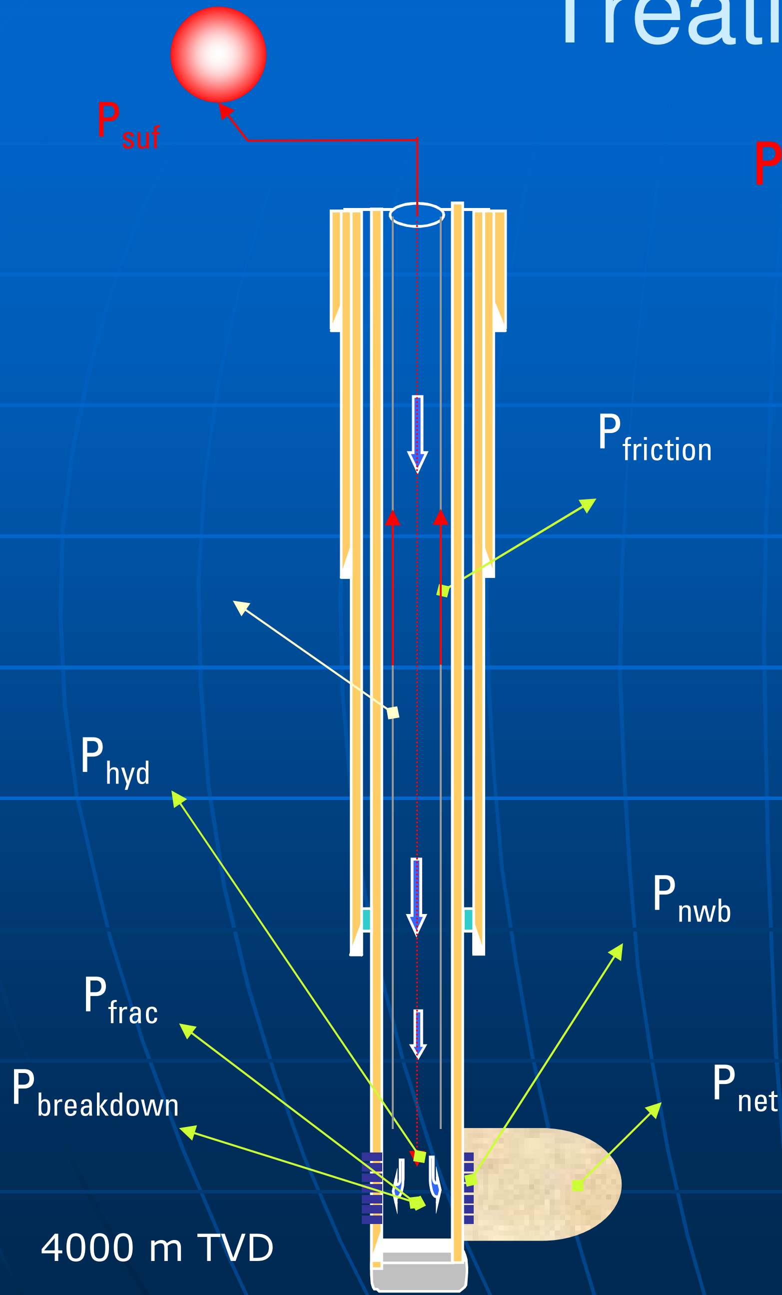
Tight Gas Sand Fracturing Design



- *Where to initiate frac ?*
- *Staging/zonal coverage ?*

1. Data Integration / Zoning
2. Identify Pay Zone
3. Identify Frac Units
4. Staging & Perforations

Treating Pressure



$$P_{suf} = (P_{BD}) + \underline{P_{frac}} - \underline{P_{hyd}} + \underline{P_{net}} + \underline{P_{fric}} + \underline{P_{nwb}}$$

P_{frac}	P_{hyd}	P_{net}	P_{fric}	P_{nwb}
Predict	**High Density (?)**	**Predict**	**Fluid Property**	**Minimize**

- Breakdown Gradient = 1.2 psi/ft (0.27 bar/m)
- NWB Friction = 1000 psi (69 bar)
- Fluid Friction = 340 psi (23 bar) @ 8 BPM

$P_{suf} = P_{BD} - P_{hyd} + P_{fric} + P_{nwb}$
$P_{suf} = 1080 \text{ bar} - 396 \text{ bar} + 23 \text{ bar} + 69 \text{ bar}$
$P_{suf} = 776 \text{ bar}$

- Frac Gradient = 1.0 psi/ft (0.23 bar/m)
- NWB Friction = 1500 psi (103 bar)
- Net Pressure = 1000 psi (69 bar)
- Fluid Friction = 1700 psi (117 bar) @ 30BPM

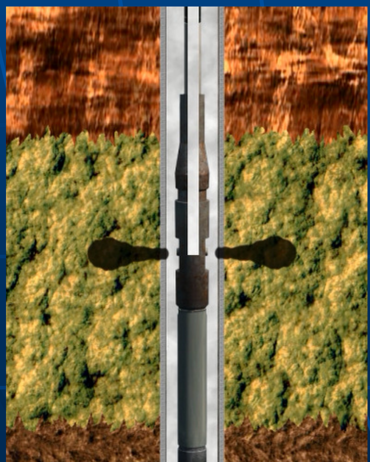
$P_{suf} = P_{FRAC} - P_{hyd} + P_{fric} + P_{nwb} + P_{net}$
$P_{suf} = 920 \text{ bar} - 396 \text{ bar} + 117 \text{ bar} + 103 \text{ bar} + 69 \text{ bar}$
$P_{suf} = 813 \text{ bar}$

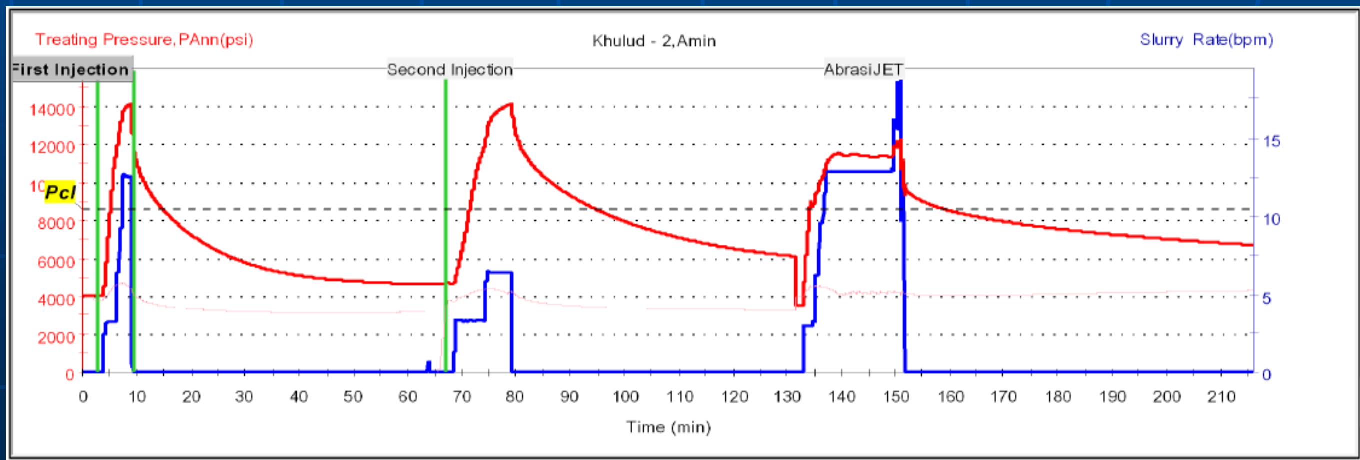
Achieving a Better NWB Connection

- Connection between wellbore and hydraulic fracturing (through perforations) are extremely important for:
  - Formation Breakdown → stress concentration
  - NWB friction –perforations / tortuosity → proppant admittance

- Basic perforation requirements:
  - Penetration: 4~6 in (~12 cm) into formation
  - Perf hole size: 9 x D_{pr_ave}
  - 2 shots / BPM
  - 60 º phasing

- Abrasive jetting has been applied in several HTHP wells onshore Europe to lower down breakdown pressure, perforation friction



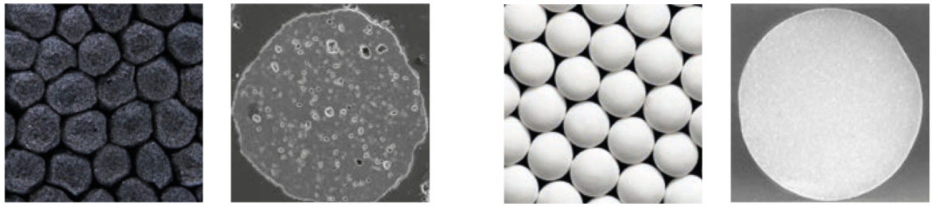


Additional Technology

Ultra High Strength Proppant Technology

CARBO KRYPTO SPHERE

- Retains integrity at 20,000 psi closure
- Single mesh size product (any size)
- Twice baseline conductivity at 20,000 psi compared to typical HSP
- Spherical shape and smooth surface to significantly reduce erosion

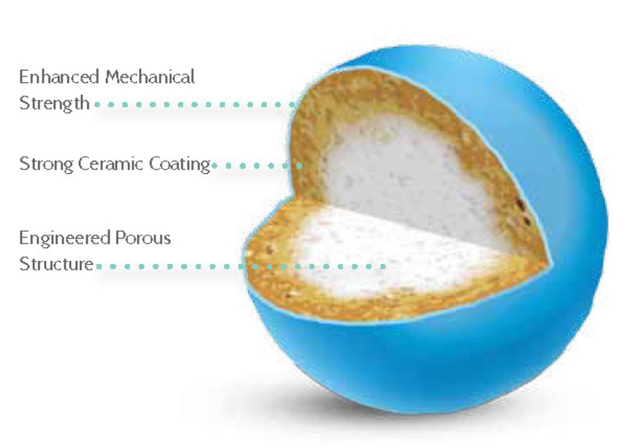


High-strength proppant
Irregular size and shape with manufacturing imperfections.

KRYPTOSPHERE
Uniform size and shape with exceptional microstructure.

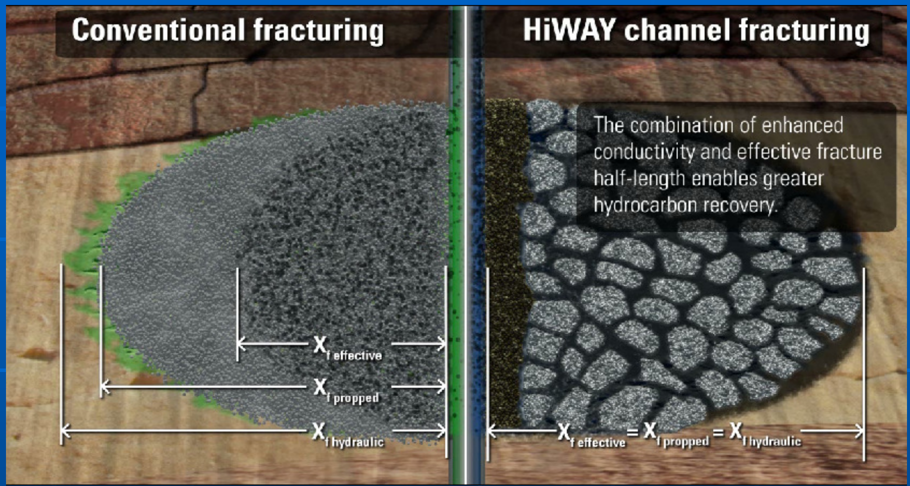
SAINT GOBAIN TITAN 3050

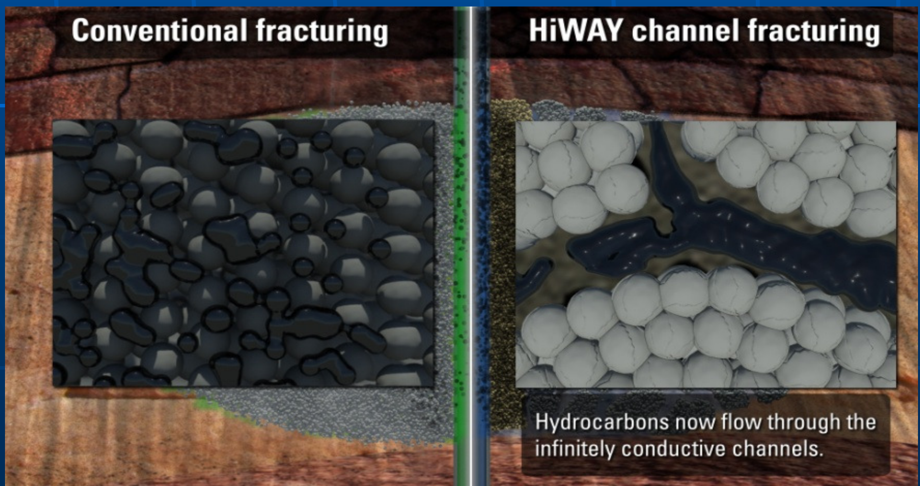
- Industry’s first beyond conventional
- Rated 20000, 25000, 30000 psi
- Available in 30/50 meshh



HiWay* Flow Channel Frac Technology

More Value with Less Resources Demanding





Reliable service, proven solution

- **> 13,800** treatments (**> 1,200** wells) in **16** countries
- Variety of formations (carbonate, sandstone, shale)
- Unprecedented proppant placement rate (**99.9%**)
  - **~ 700** screen-outs prevented to date

Significant impact on production

- **>20%** increase in tight formations

Significant reduction in logistics, safety risks and environmental footprint. Reductions in:

- Water and proppant consumption per job of **25%** and **42%,** respectively;
- **> 540 million** gallons of water and **> 1.8 billion** lbs of proppant saved so far;
- **> 80,000** proppant and water hauling road journeys
- **~ 18 million** lbs of CO_2 emissions avoided

Paradigm shift in hydraulic fracturing technology

21

Conclusion

- Fracturing fluid technology developments facilitate the challenges of ultra-high-temperature reservoirs.

- Success of hydraulic fracturing in HTHP wells lies on the application of proper workflow, includes multi-discipline contributions:

  - Materials technology for HTHP application
  - Reservoir description and data integration
  - Proper staging to achieve optimum zonal coverage
  - Proper perf strategy to minimize treating pressure

- Based on well conditions, “out of box” additional technology may be tested to evaluate its applicability onshore Europe.

Thank Your

&

Discussions